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EMC and Power Quality Standards for 20-kHz Power Distribution

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EMC AND POWER QUALITY STANDARDS FOR 20-kHz POWER DISTRIBUTION

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Abstract

The Space Station Power Distribution System has been baselined as a sinusoidal single phase, 440 VRMS, 20 kHz system. This system has certain unique characteristics that directly affect its application. In particular existing systematic description and control documents were modified to reflect the higher operating frequency.

This paper will discuss amendments made on Mil STD 704 ("Electrical Power Characteristics"), and Mil STD 461-B ("Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference").

In some cases these amendments reflect changes of several order of magnitude. This paper will discuss some of the implications and impacts of these changes.

Background

The 20 kHz Space Station Power Management and Distribution (PMAD) System has several unique characteristics which directly enhance both user power quality, and electromagnetic emission control. In order to define and codify these characteristics existing MIL Specifications were amended to represent the newer conditions. Two such specifications containing modifications are: "Space Station Electrical Power Standard" JSC 30482 (MIL-STD-704 Amended) and "Space Station Electromagnetic Emission and Susceptibility Requirements for EMC" JSC 30237 (MIL-STD-461-B Amended).

System Characteristics

The Space Station Power System delivers power by means of a 20 kHz, single phase, sinusoidal, high voltage. Although a distribution frequency of 20 kHz appears to be high when first encountered, the fact that a regulated, low distortion, sinewave is involved greatly limits the wide frequency noise spectrum commonly associated with switched mode power converters.

As the voltage is regulated variations in delivered power cause an amplitude modulation of the 20 kHz current waveform. The harmonics represented by modulation of the current waveform will be contained in sidebands clustered about the 20 kHz "carrier." As an example a current waveform supplying a 400 Hz single phase load is illustrated in Fig. 1. As power is delivered by a sinusoidal wave and even the most severe current distortions involve only the first two odd harmonics, essentially the total noise spectrum will be contained in bands of frequencies occurring at multiples of the carrier and two others of reduced amplitude clustered about the third, (60 kHz) and the fifth (100 kHz) harmonics. This limited source energy spectrum has two advantages: no appreciable system energy is transmitted at the frequencies of most interest to the science community (0 to

10 kHz), and the energy actually transmitted is confined to a few, well defined frequency bands.^{1,2}

At the load end of the system lower frequencies, if required, will be synthesized from the 20 kHz carrier. The synthesis scheme used will allow the low frequency amplitude, and waveform to be controlled independently. Independent control to these two variables again limits the energy spectrum, which in turn results in a inherently "clean" system. A study of low frequency synthesis was performed at the University of Wisconsin at Madison.³ Some results of that effort are shown in Fig. 7. Shown are a computer simulation of one phase of a three phase 400 Hz converter. The waveform taken from an operating breadboard, and a spectrum analysis performed upon the breadboard output.

Power Feeder Cables

The design of the feeder cables has a direct impact on both the power quality, and the systems ability to avoid susceptibility (cross talk). To meet the simultaneous requirements of High Efficiency, Low Cross Talk, and low external radiation a three conductor "flat" cable was developed (Fig. 3). This cable is essentially a double sided strip line with a very low characteristics impedance. The equivalent circuit for this cable would be a low pass filter section with a low inductance, relative high capacitance, and a corner frequency above 100 kHz. The cable/system is designed to provide power with (+2.5 percent) total regulation/cross talk. As a result of this low impedance, this system is remarkably tolerant of current distortion. To illustrate this point a 25 KW source driving 50 m of flat transmission line was loaded with an intentionally distorted current waveform (Fig. 4). As shown, in a third harmonic current distortion of over 40 percent resulted in a third harmonic voltage distortion of less than 4 percent (Fig. 5). The actual levels of total current distortion allowed on the space station will be controlled to levels much less than those used in the experiment.

Space Station Electrical Power Standard JSC 30482 (MIL-STD-704 Amended)

As indicated by the title the power standard is MIL-STD-704 modified to reflect the higher operating frequency. The normal operation steady state characteristics are shown in Figure 7. One significant difference in the amended standard is the expansion of the definition of abnormal operation to comprise three classes of failure in order to accommodate the redundancy of the Space Station Power System. Another amendment is the reduction of transient voltage envelope to a maximum of +10 percent, (was +56 to -30 percent) and reducing the envelope duration to 1 msec (was 80 msec). These amendments basically reflect the improvements achieved by electronic power conversion as opposed to rotating machine response.

Electromagnetic Control Specifications (EMC)

For the Space Station the EMC Requirements are specified by JSC-30237 "Space Station Electromagnetic Emission and Susceptibility Requirements for EMC." (Mil-STD 461-B Amended).

These specifications have been amended to provide a lower radiated emission environment for the science payloads located on the upper and lower boom. For example, RE Q2 Broadband limit allows an additional 32 Db reduction in the scientific areas.

At present it is also intended to apply different level specifications to individual equipment and to integrated systems. As an example magnetic radiation would be measured at 7 cm (Mil-STD 462) at the equipment level, but the measurement would be made at 1 m on the integrated system. This procedure will allow greater than 20 Db additional margin for system effects.

Other than these modifications the external (emission) specifications of Mil STD 461-B will remain unchanged.

Viewing the Power Distribution System as an end-to-end entity from the source to the user interface conducted interferences, not effecting systematics, are of concern only to the extent that they involve radiation. To the extent that the total system has not been either designed or evaluated the conducted interference have largely represented power system requirements and capabilities.

Conducted Susceptibility Test CS01-B

In the High Frequency Distribution System conducted susceptibility addresses the response of

attached equipment to distortion of the distribution voltage waveform. CS01-B requires equipment to operate under the conditions defined by JSC 30482 (power quality). This basically defines a response to harmonic distortion under normal and abnormal conditions.

For 20 kHz AC power both the susceptibility and conducted interference specifications will be referenced to harmonic distortion of the supply voltage and the supply current.

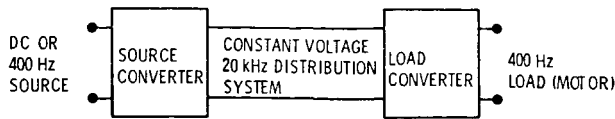
Remaining to be Specified

1. An improved flat cable constructed in a more dimensionally stable manner will further reduce the magnetic field radiated at 20 kHz.
2. A determination of the module distribution architecture and bus impedance must be made before final conducted interference specifications may be created to define user interfaces.
3. Modeling must be developed to predict systematic effects and to intelligently grant specification waivers.

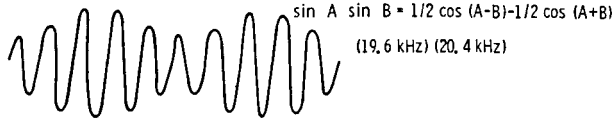
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1. Mildice, J., "AC Power System Test Bed," NASA CR-175068, 1986.
2. Hansen, I.G. and Wolff, F.J., "20 Kilohertz Space Station Power System," NASA TM-88801, 1986.
3. Lipo, T.A. and Sood, P.K., "Study of the Generator/Motor Operation of Induction Machines in a High Frequency Link Space Power System," NASA CR-179600, 1987.

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- THE DISTRIBUTION VOLTAGE REMAINS CONSTANT
- THE DISTRIBUTION CURRENT WILL BE 20 kHz WITH A 400 Hz AMPLITUDE VARIATION



- THE ENERGY SPECTRUM OF THE DISTRIBUTION SYSTEM CONTAINS ONLY 19.6 kHz, 20.0 kHz AND 20.4 kHz
- THERE IS NO LOW FREQUENCY EMI SOURCE PRESENT IN THE DISTRIBUTION SYSTEM

FIGURE 1 CURRENT MODULATION

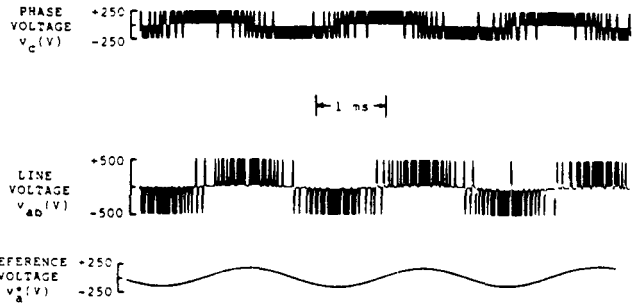


FIGURE (1b) COMPUTER SIMULATION OF LOW FREQUENCY SYNTHESIS
(2a) (UNIVERSITY OF WISCONSIN)

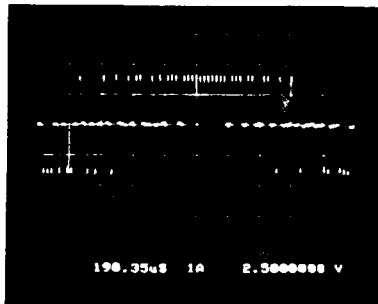


FIGURE (2b)

Output of breadboard synthesizer
(University of Wisconsin)

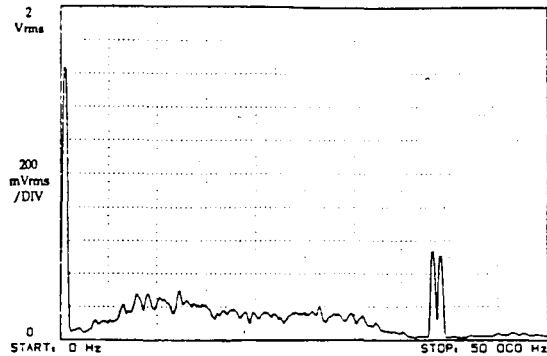


FIGURE (2c)

Spectrum of breadboard
Synthesizer (University of
Wisconsin) (1st Sideband Set)

FIGURE 2

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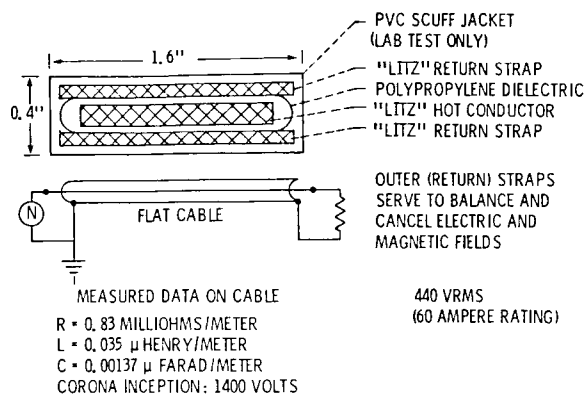


FIGURE 3 FLAT CABLE

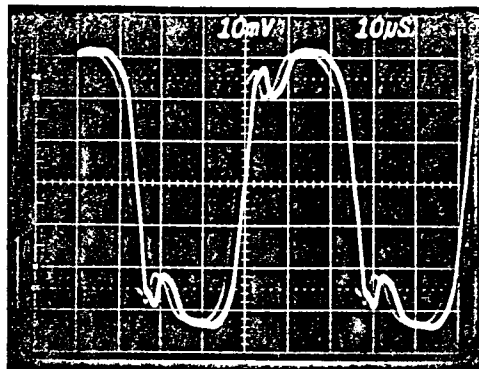
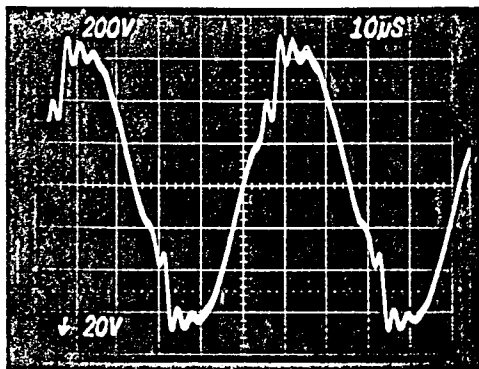


FIGURE 4 CROSS TALK AT RECEIVER WITH NO INPUT FILTER

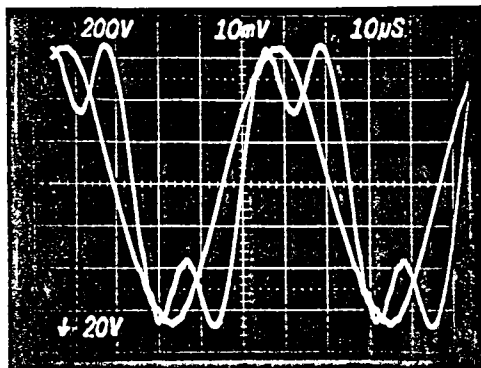


FIGURE 4-a
CROSS TALK WITH FILTERS

RECEIVING AND BUS CURRENT			RECEIVING END BUS VOLTAGE		
f (kHz)	dBA (Ir)	%i/Ir	f (kHz)	dBV (Vr)	%v/Vr
0	-88.00	0.00%	0	-100.30	0.00%
20	0.00	100.00%	20	0.00	100.00%
40	-51.60	0.26%	40	-50.60	0.30%
60	-7.70	41.21%	60	-27.80	4.07%
80	-47.00	0.45%	80	-45.70	0.52%
100	-29.30	3.43%	100	-29.40	3.39%
120	-64.70	0.06%	120	-60.90	0.09%
140	-39.80	1.02%	140	-39.70	1.04%
160	-64.20	0.06%	160	-59.20	0.11%
180	-46.40	0.48%	180	-46.70	0.46%

FIGURE 5 VOLTAGE AND CURRENT
DISTORTION MEASUREMENTS

AC NORMAL OPERATION STEADY STATE CHARACTERISTICS

From JSC 30482 Mil STD 704 Amended

CHARACTERISTICS	LIMITS
Voltage	429 to 451 volts
Waveform distortion factor	0.03 maximum
Waveform distortion spectrum	Figure 1
DC component	+0.10 to -0.10 volts
Frequency	20 kHz \pm 0.5%

FIGURE 6 STEADY STATE

AC ABNORMAL OPERATION CHARACTERISTICS

CHARACTERISTIC	FAILURE LEVEL (See Note (1))	LIMITS
POWER DROP OUT	ONE	TBD MICROSECONDS (50 TYPICALLY)
	TWO	TBD MILLISECONDS (500 TYPICALLY)
WAVE FORM DISTORTION FACTOR	ONE	NO CHANGE
	TWO	TBD
WAVE FORM SPECTRUM	ONE	NO CHANGE
	TWO	TBD
FREQUENCY DEVIATION	ONE	NO CHANGE
	TWO	TBD
VOLTAGE	ONE	NO CHANGE
	TWO	TBD

NOTE 1. The electrical power system is multiply redundant and reconfigurable. The power standards which apply to any particular load is a function of the load priority and the level of the system failure. For purpose of this classification a level one failure involves the loss of one of several power feeder paths. Level two failures represent the loss of an additional feeder, or an energy source.

Level two failure accommodation involves failure analysis, load shedding, and system reconfiguration. Safe Haven operation concerns level three failures involving major portions of the power system.

FIGURE 7

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